The Challenges of Landing on Uncertain Terrain

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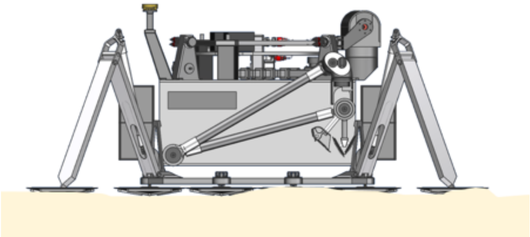
Factors for Judging Landing Success

Factor 0:
Hardware
Integrity/Health

Power Availability

DDL Contamination
& Alteration of Surface

Thermal Safety



Sampling Performance

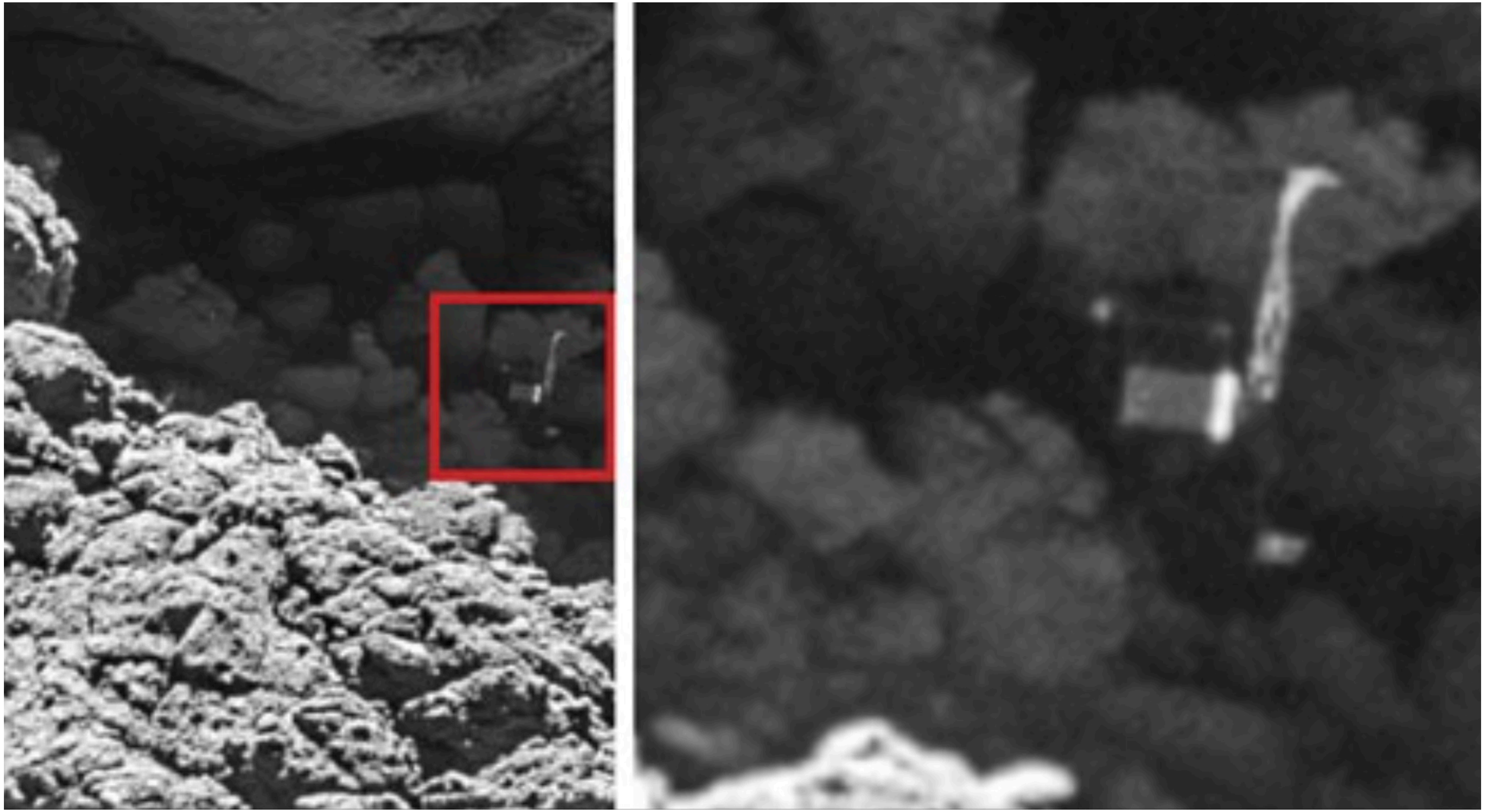
Telecom Performance

Science Relevance

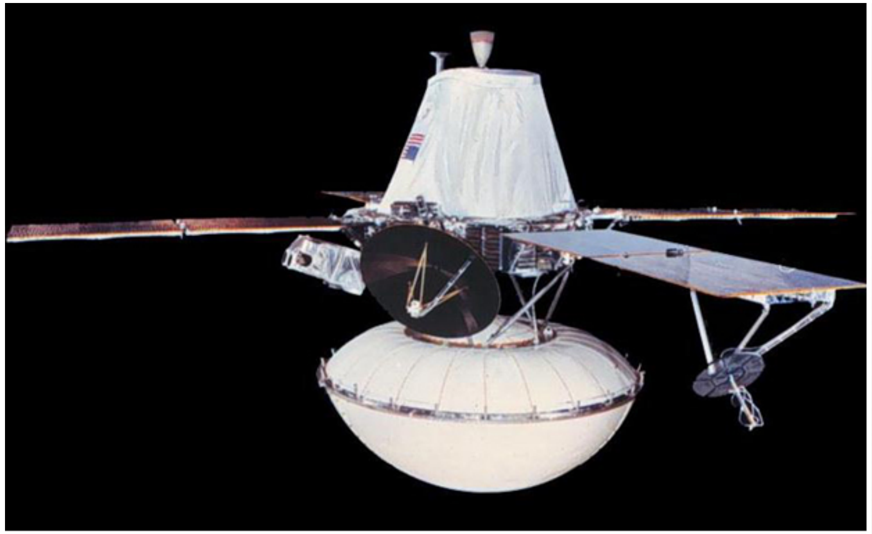
Imaging Performance

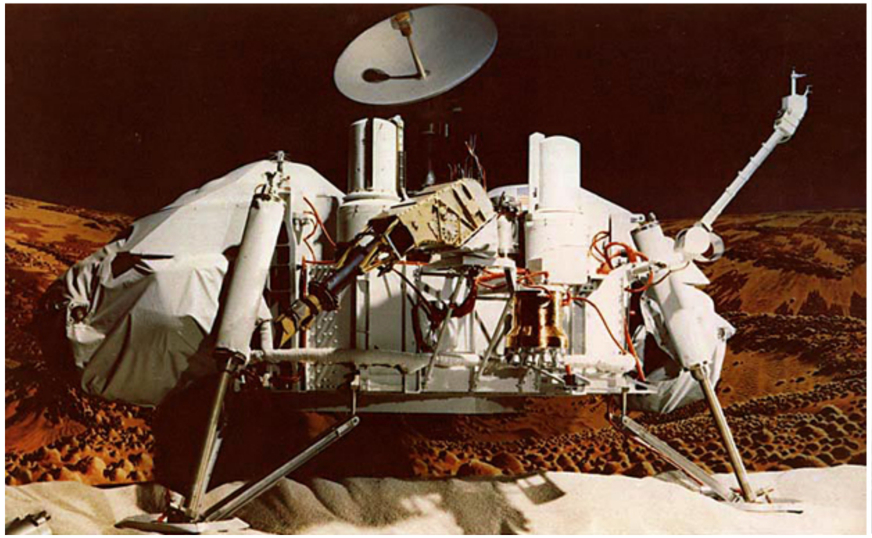
DDL Success is judged by how it impacts the success of the surface mission

Philae Lander on Comet CG



Viking I & II (1976)





Viking I and Big Joe

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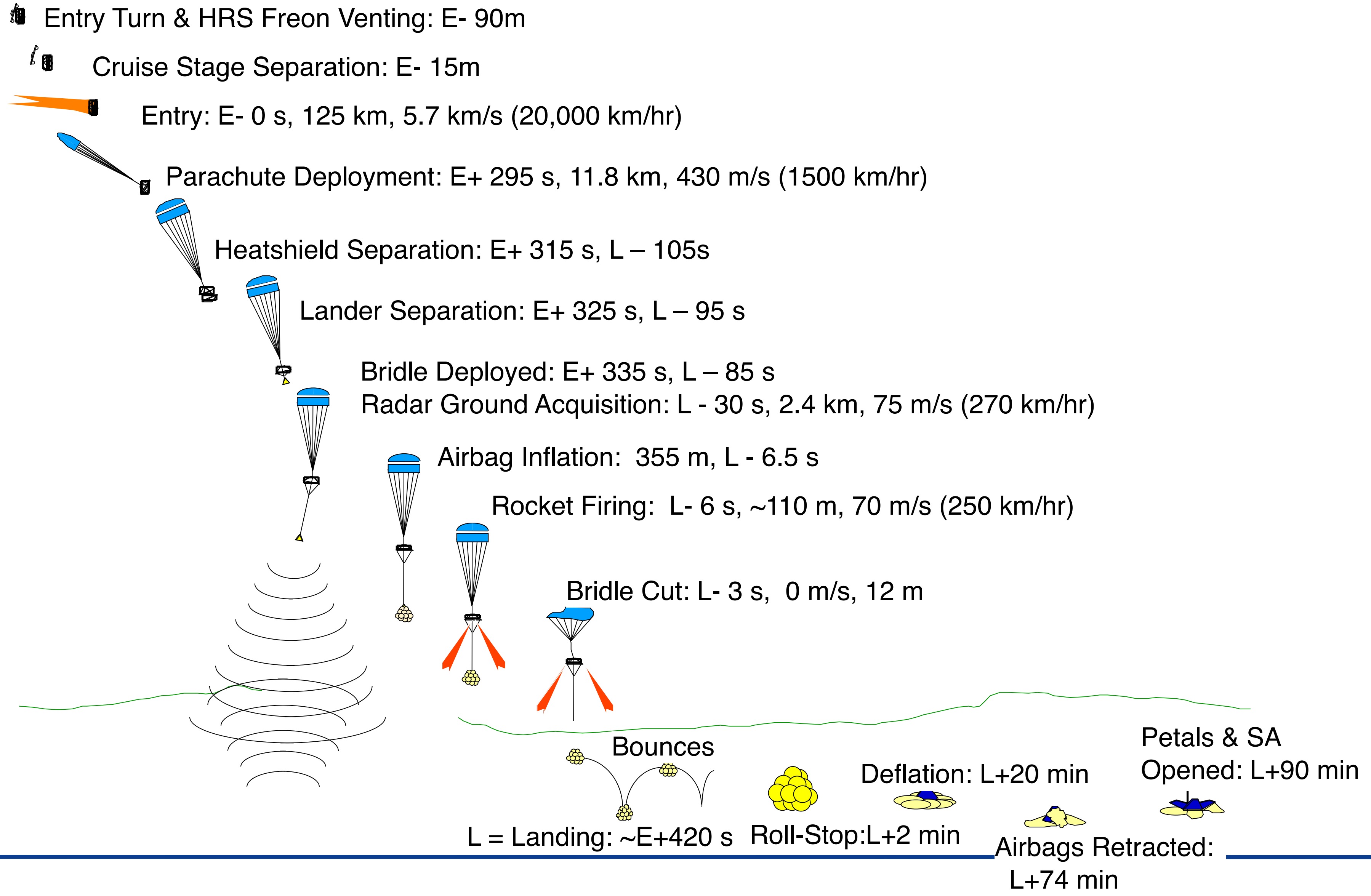
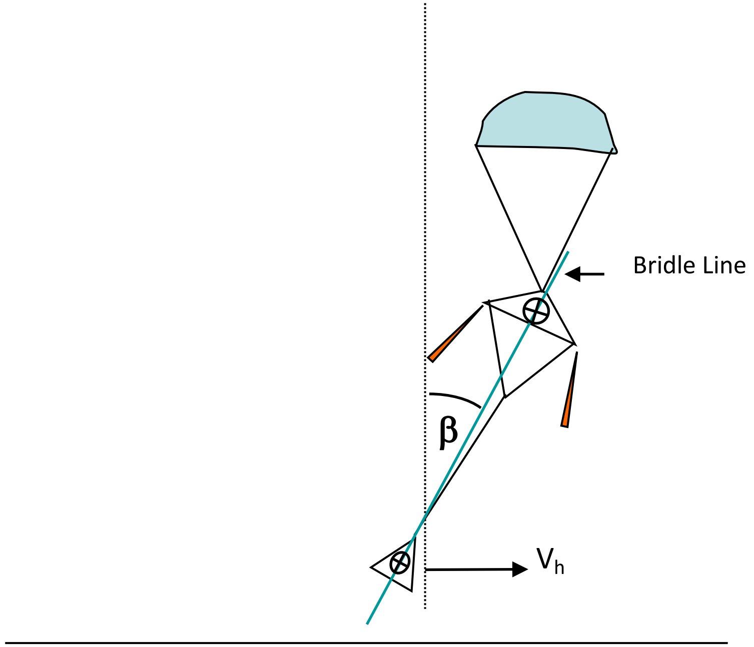
Mars Pathfinder (1997)

Entry, Descent & Landing Timeline



Wind Induced Horizontal Velocity

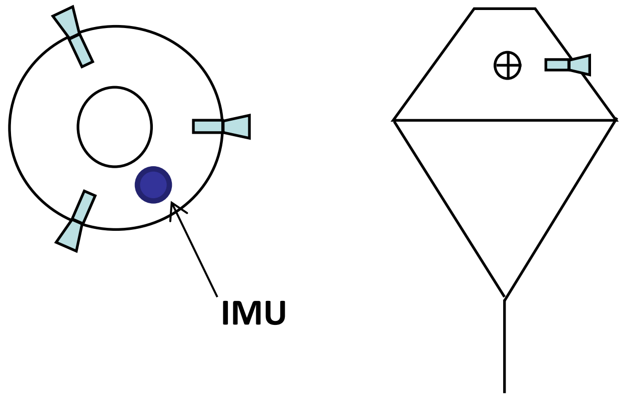
$$V_h(t_{bc}) = \overbrace{V_h(t_{RAD})}^{\text{Initial Horizontal Velocity}} + \overbrace{\int F_{RAD}/m * \sin(\beta)\, dt}^{\text{RAD Induced Horizontal Velocity}}$$

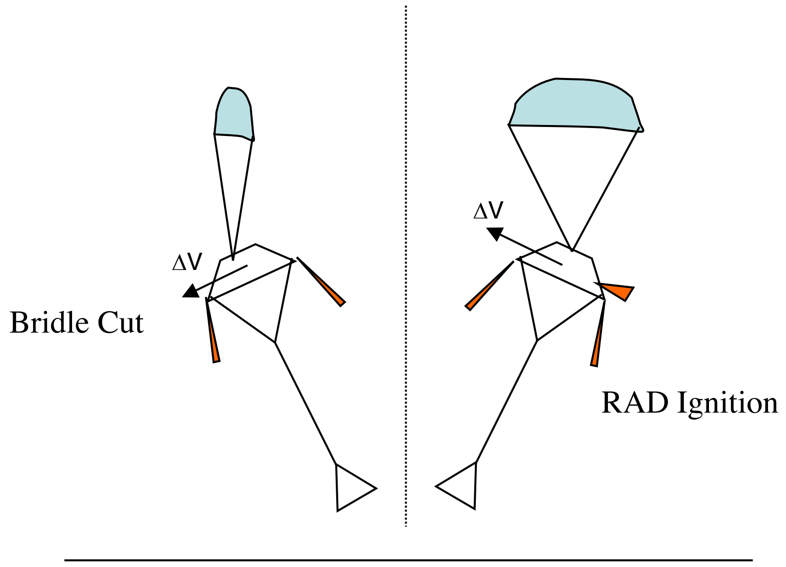


RAD Induced Horizontal Velocity

Transverse Impulse Rocket System

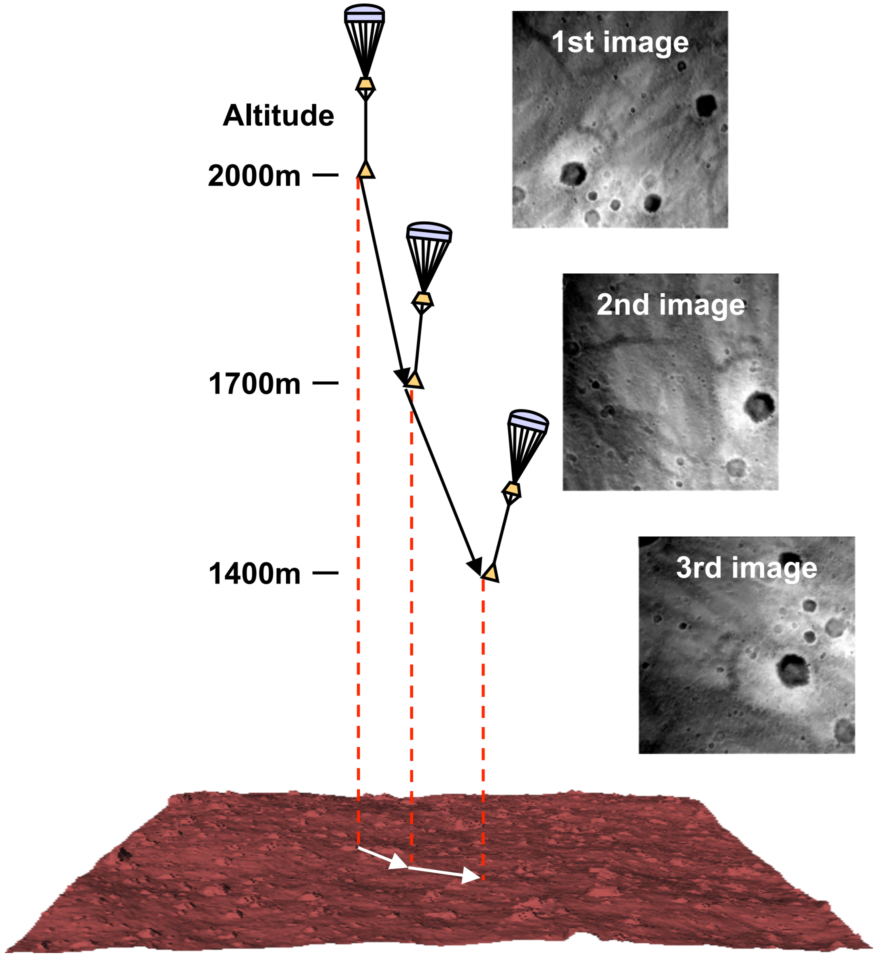
(TIRS)

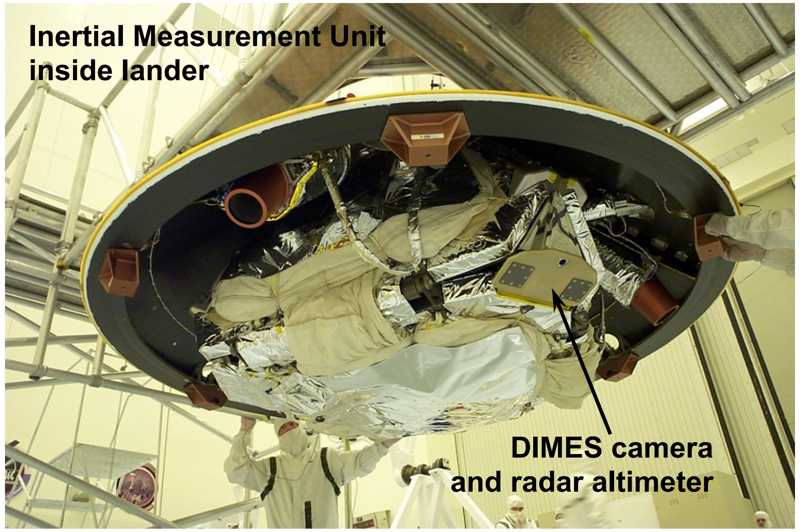




Descent Image Motion Estimation System
(DIMES)

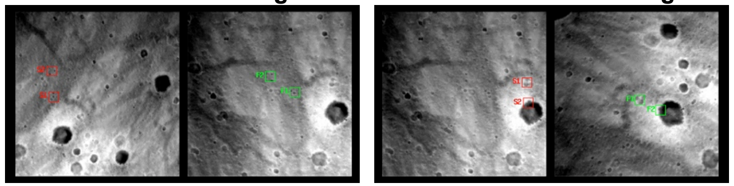
DIMES SCENARIO





DIMES RESULT

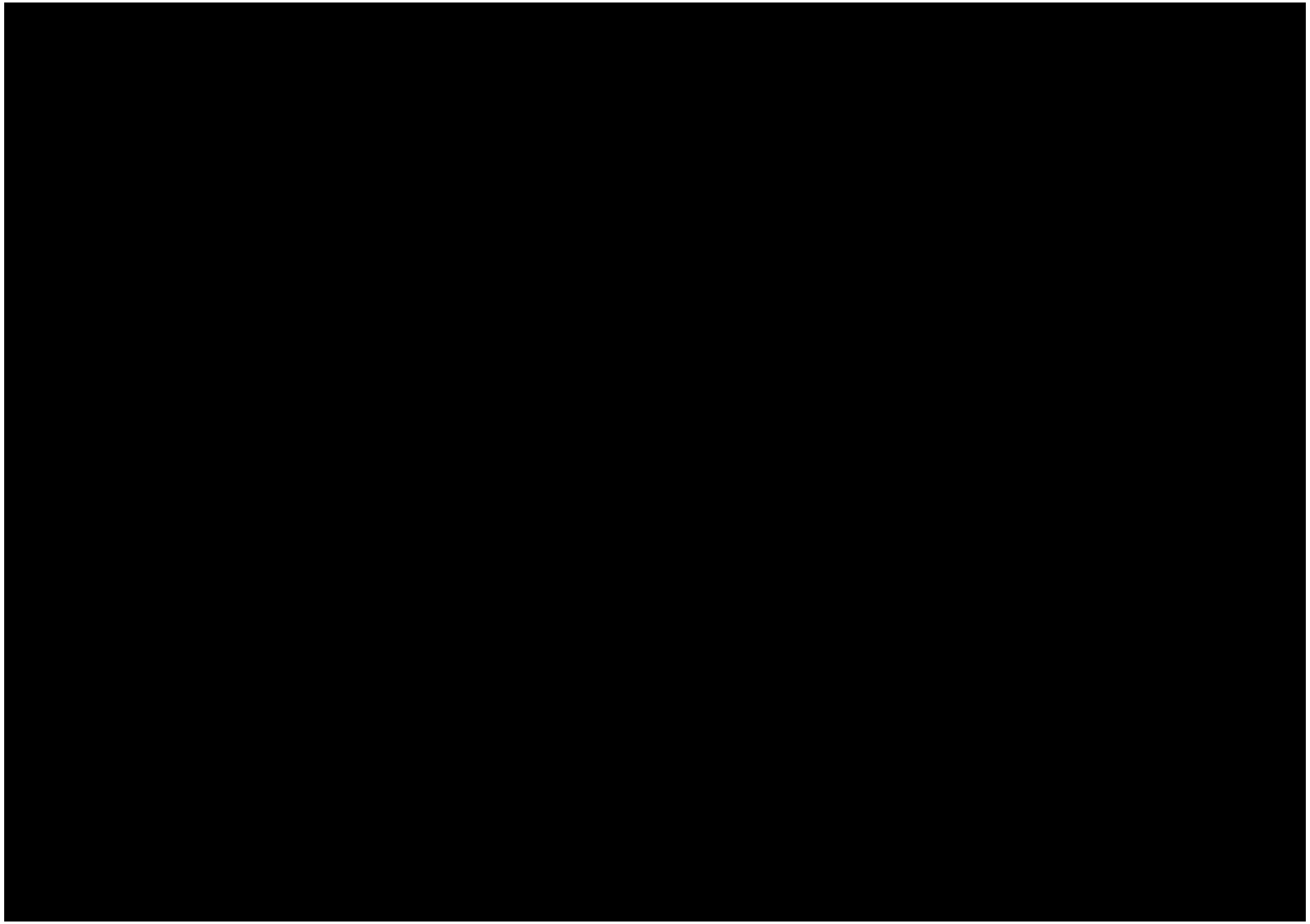
First Pair Tracking
Second Pair Tracking



MER-A/Spirit, Gusev Crater, January 4th, 2004

First use of Terrain Relative Navigation (TRN)

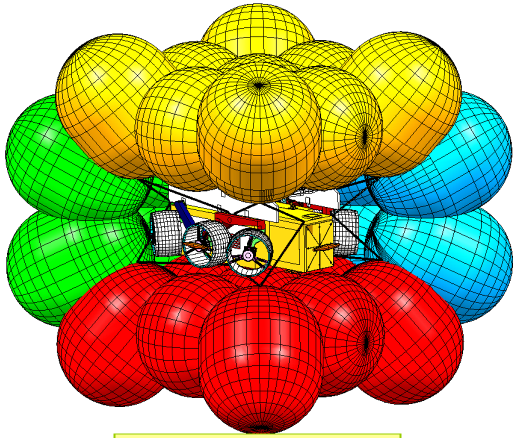
Spirit Landing in January 2004



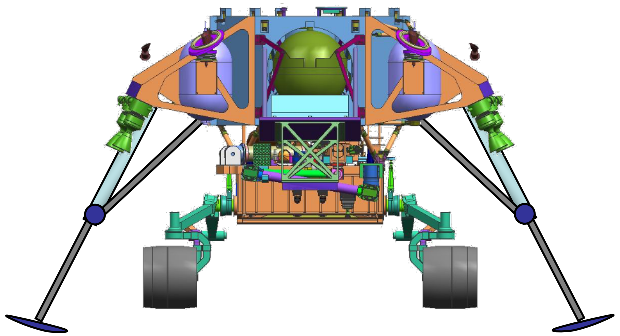
2012 Curiosity Rover

2011 Electric Mini Cooper

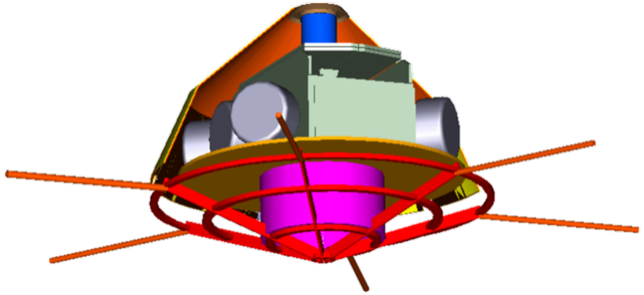
How to land a 1 ton rover on Mars?

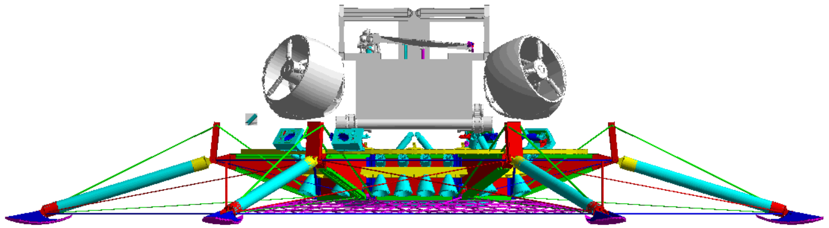


Airbags



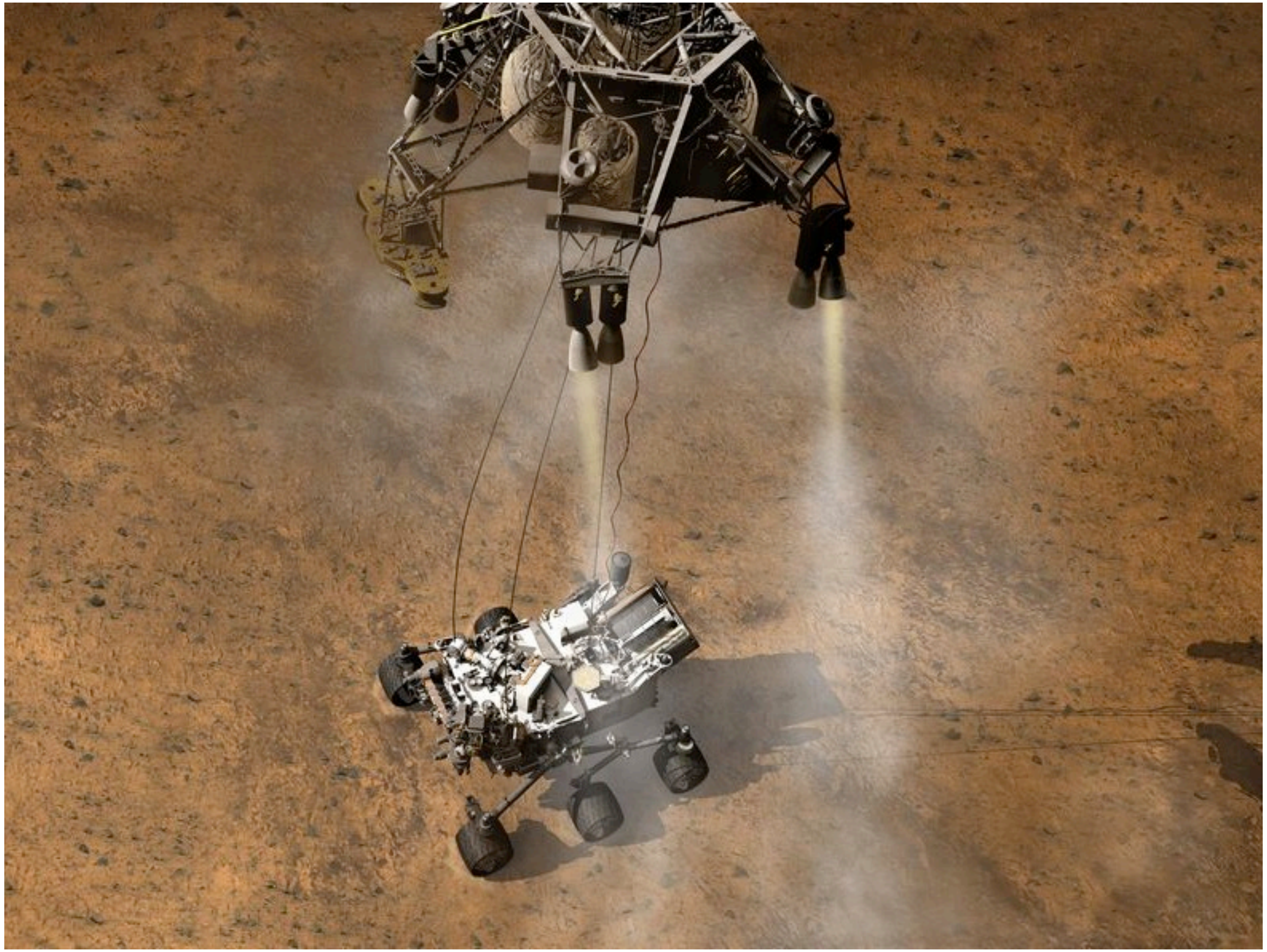
Legs



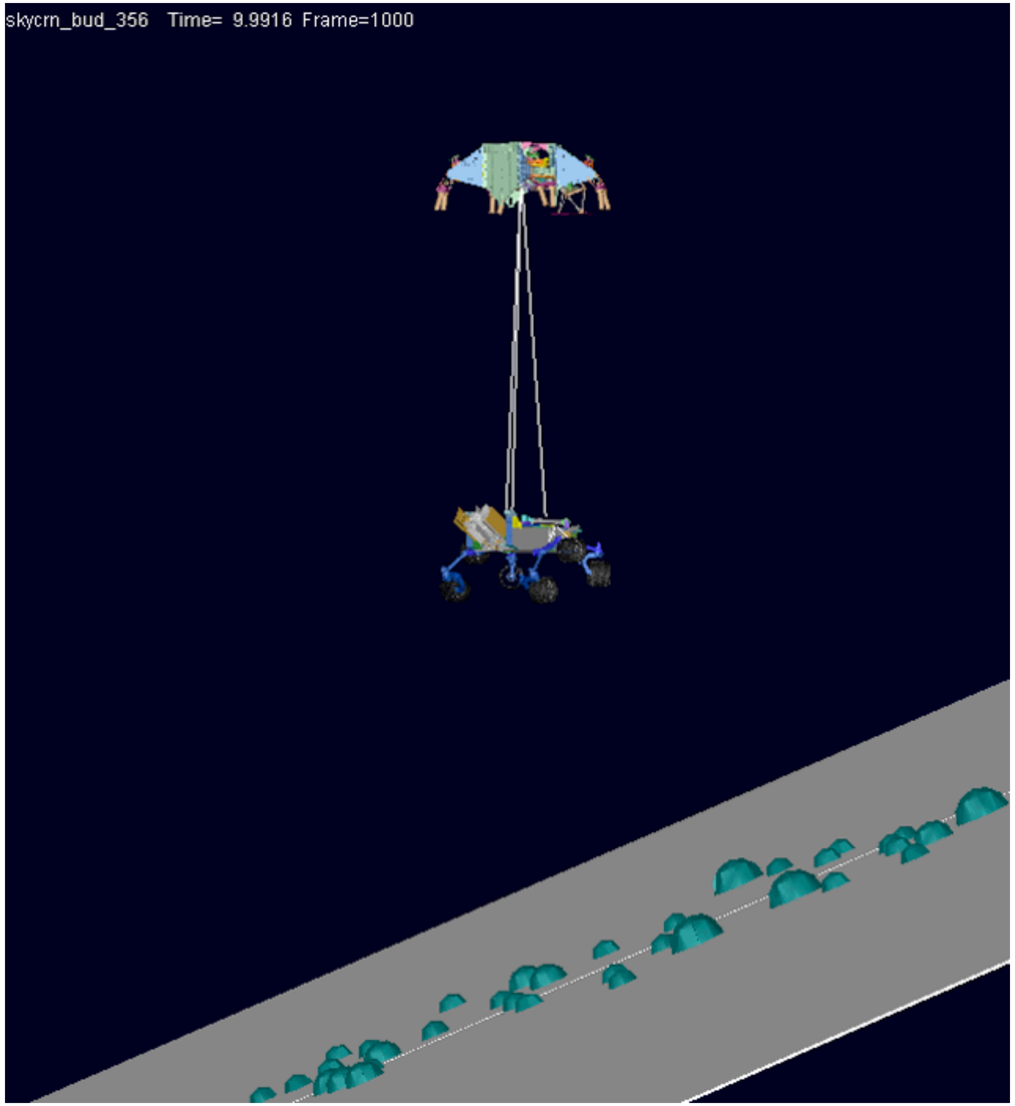


Pallet

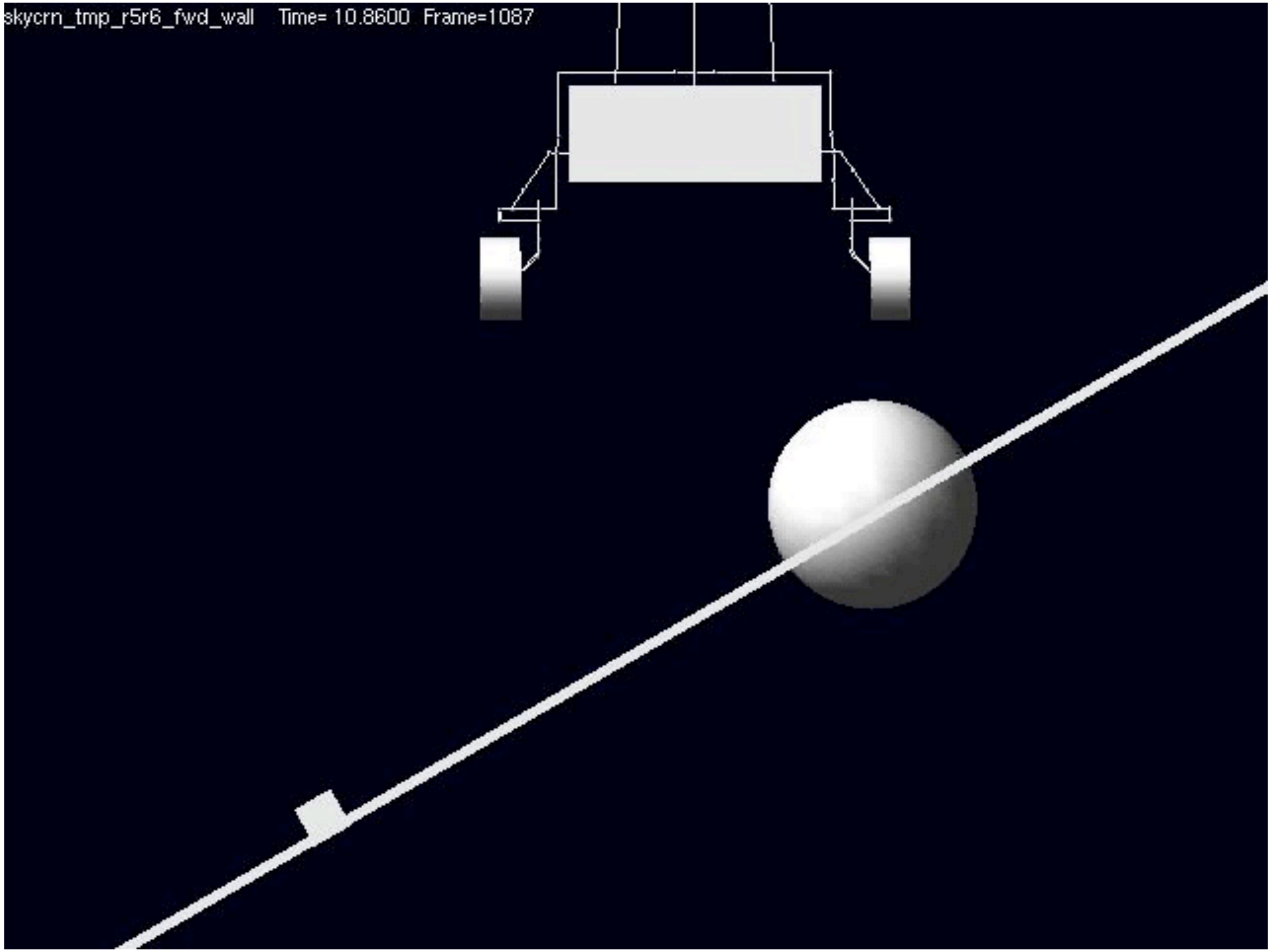
The SkyCrane is Born



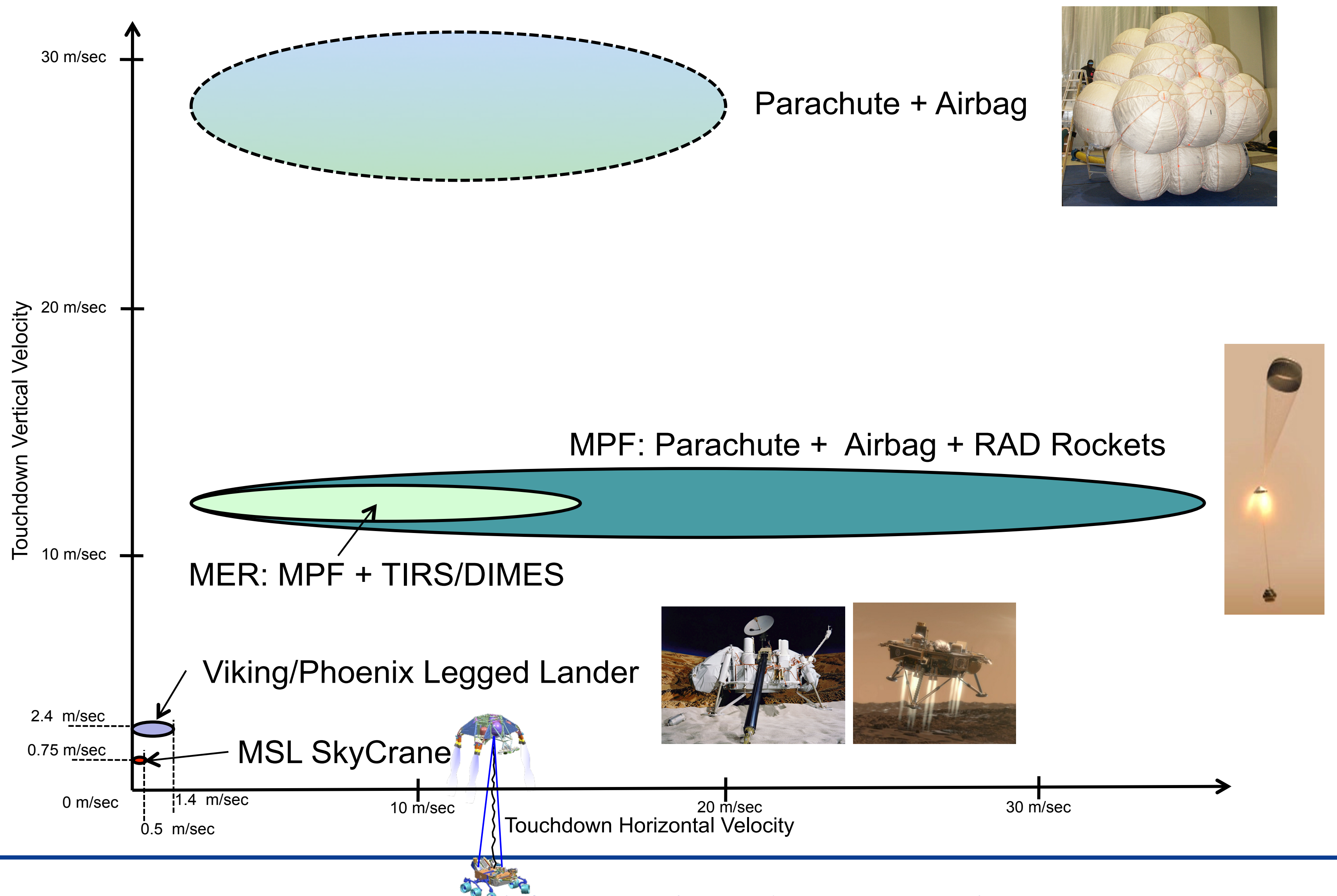
Continuous Control Through Touchdown

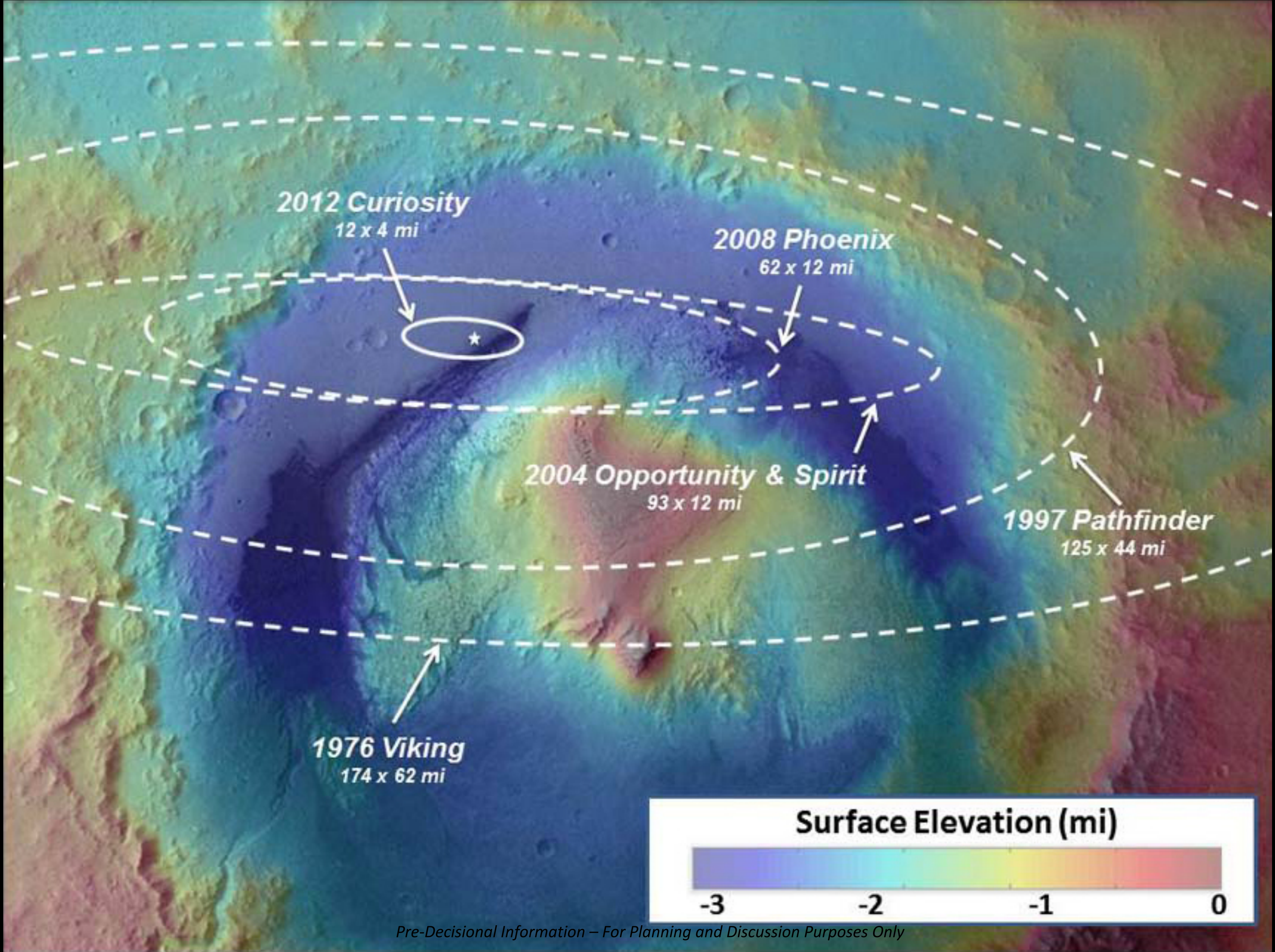


Terrain Adaptable Mobility



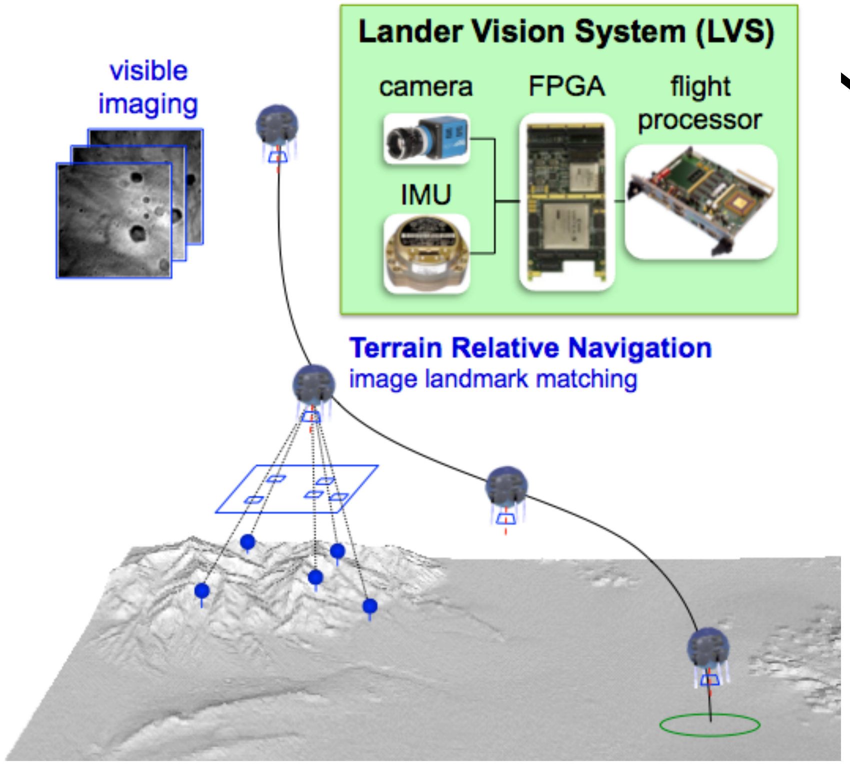
History of Mars Touchdown Velocities

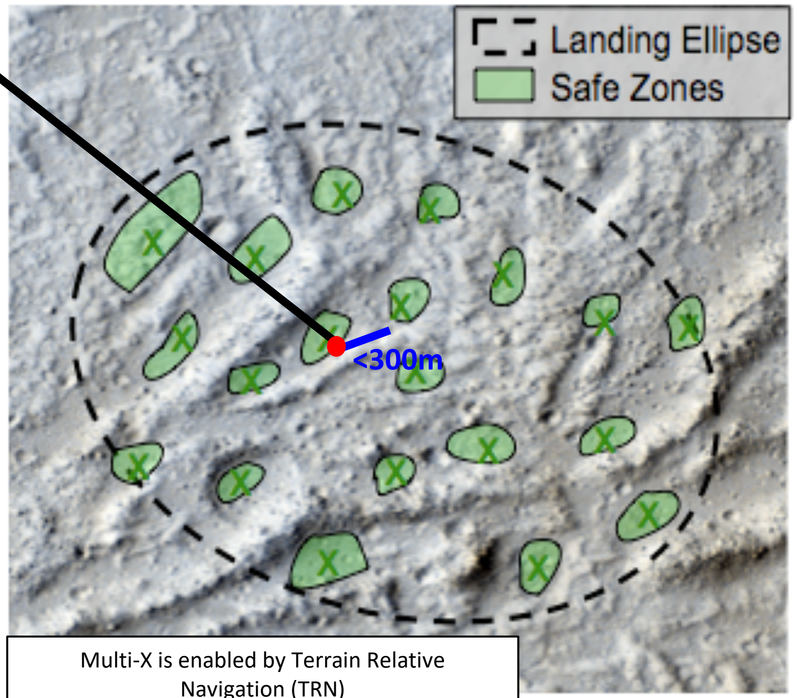




2012 Curiosity
12 x 4 mi
2008 Phoenix
62 x 12 mi
2004 Opportunity & Spirit
93 x 12 mi
1997 Pathfinder
125 x 44 mi
1976 Viking
174 x 62 mi
Surface Elevation (mi)
-3
-2
-1
0

Mars 2020: Terrain Relative Navigation





Multi-X is enabled by Terrain Relative Navigation (TRN)

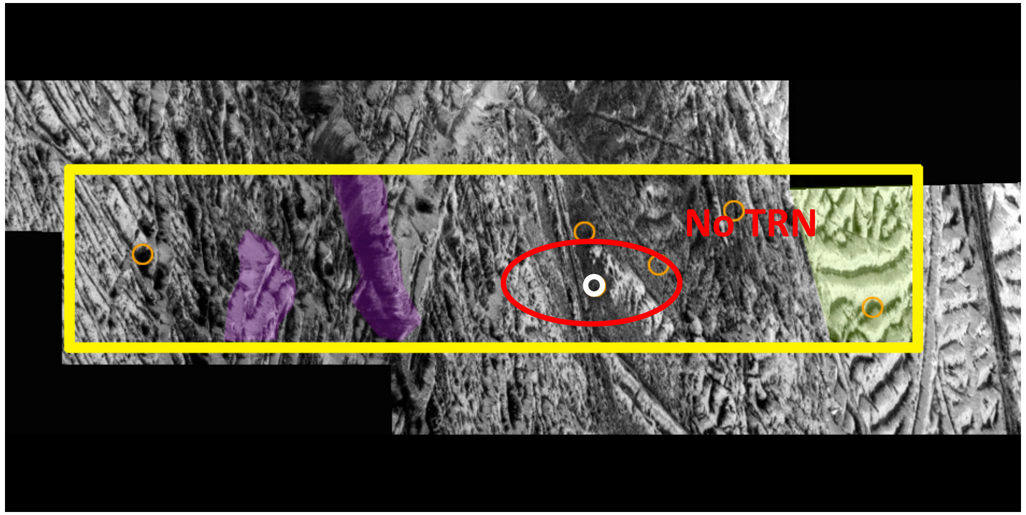
The Pillars of DDL for Europa

1. Terrain Relative Navigation (TRN) for reduced landing ellipse size
2. Hazard Detection to avoid lander-scale hazards
3. SkyCrane architecture for soft landing (i.e. Factor 0) and surface alteration avoidance
4. Adaptable Lander Stabilizers to accommodate rough terrain
5. Tolerance of radiation induced resets and failures
6. Landing Site Selection

Pillar 1: TRN-Enabled Reduced Landing Ellipse

Terrain Relative Navigation (TRN) for reduced (200m) landing ellipse size to improve the probability of finding landing areas that:

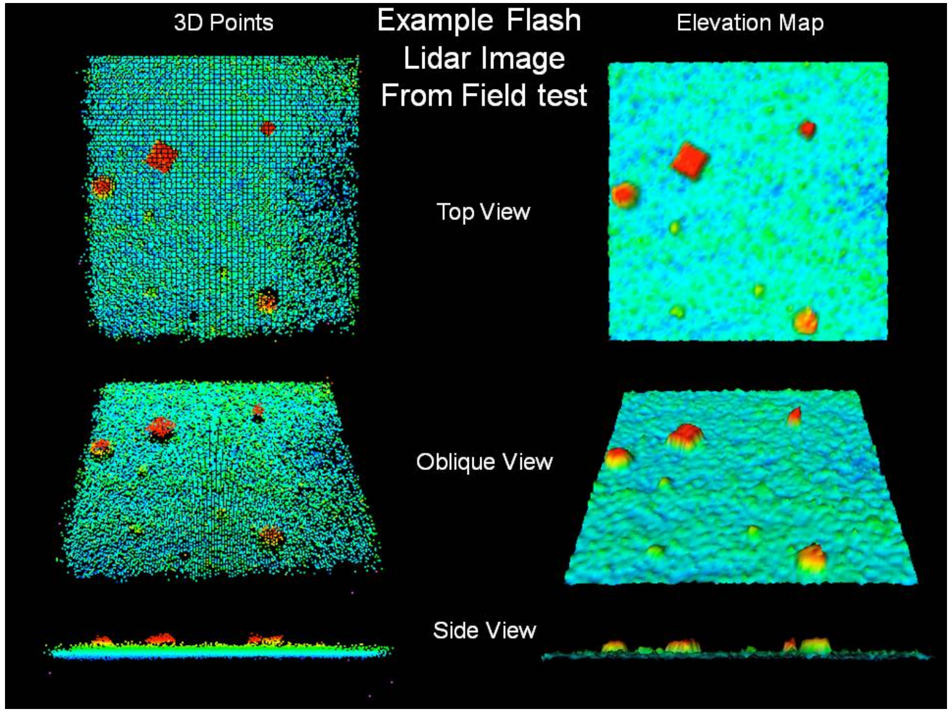
- contain relevant science within the landing area
- assure a low horizon mask for guaranteeing required telecom performance
- assure high probability of finding a flat surface at the lander scale



Pillar 2: Hazard Detection & Avoidance

On-board Hazard Detection and Avoidance to:

- land within the capability of the landing gear to achieve a close to level lander deck
- improve sample-ability of surface
- minimize horizon mask for improved telecom performance and imaging of landing area



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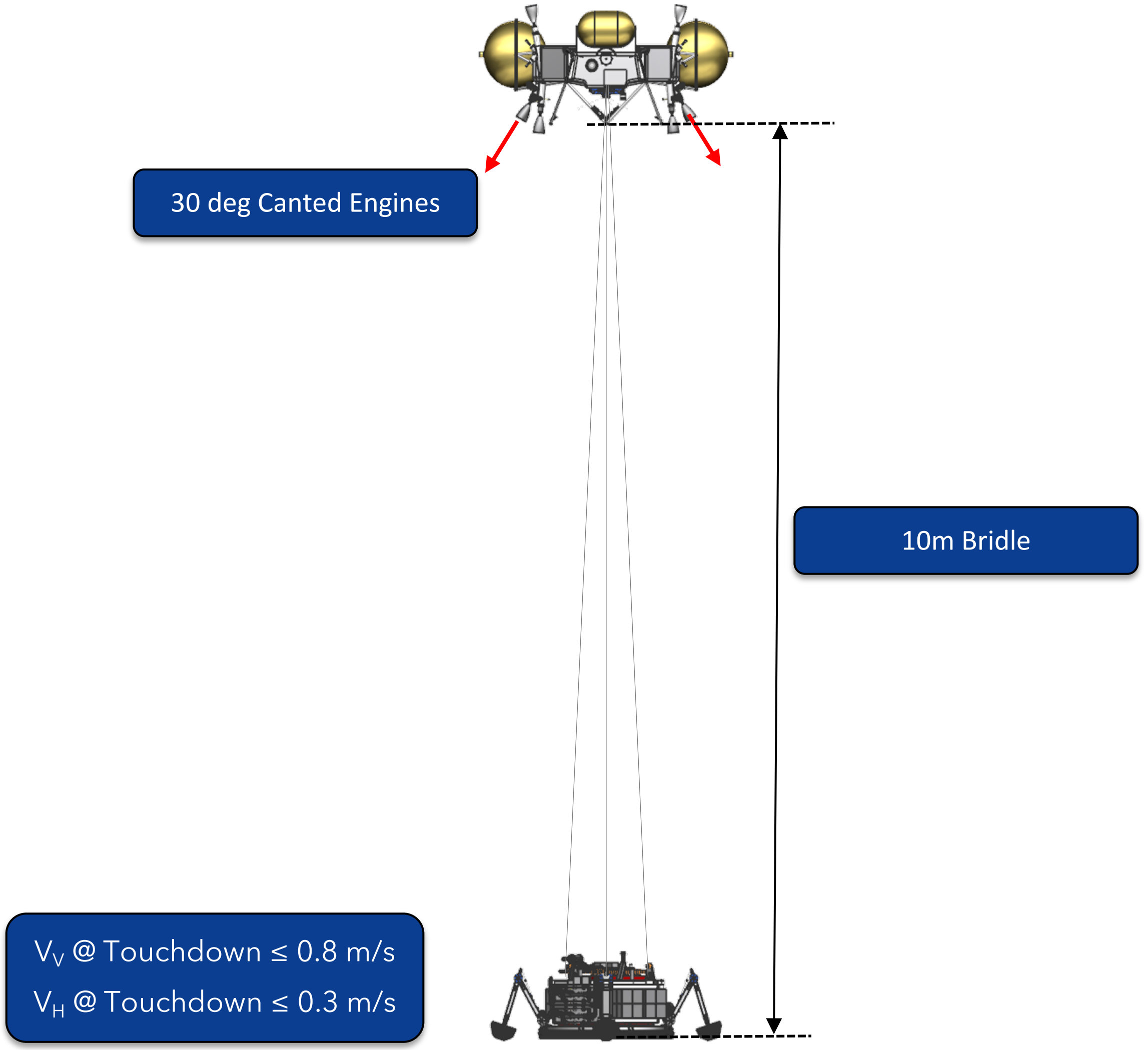
Pre-Decisional Information – For Planning and Discussion Purposes Only

Pillar 3: SkyCrane Landing Architecture

SkyCrane landing architecture to:

- enable soft landing speeds to avoid damaging the lander (i.e. Factor Zero)
- improve landing stability
- reduce surface alteration and contamination

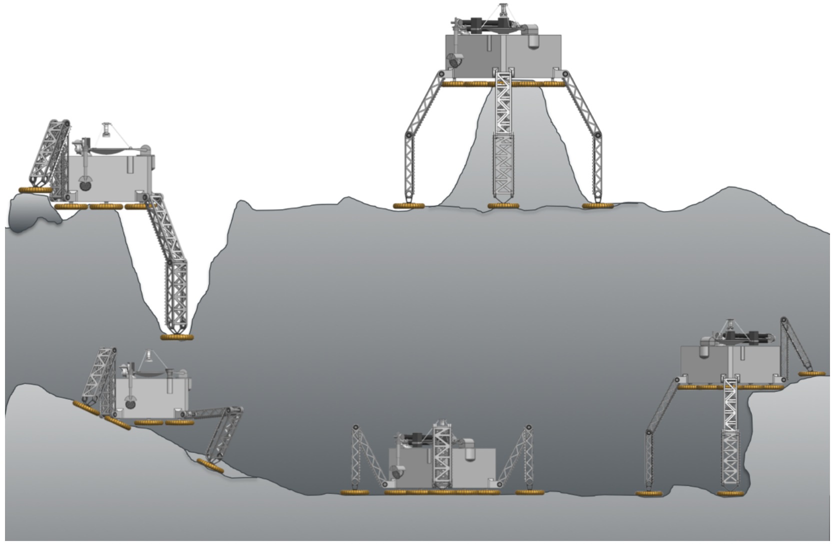


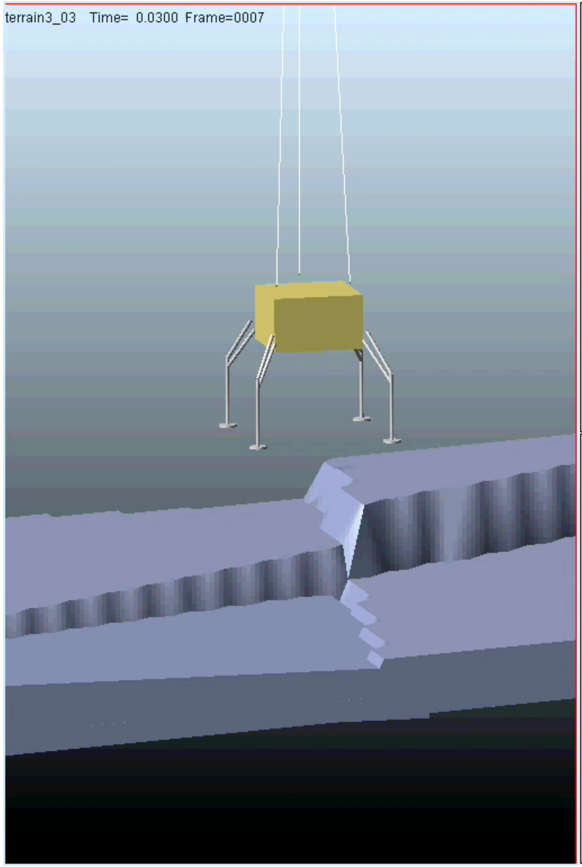
Pillar 4: Adaptable Stabilizers

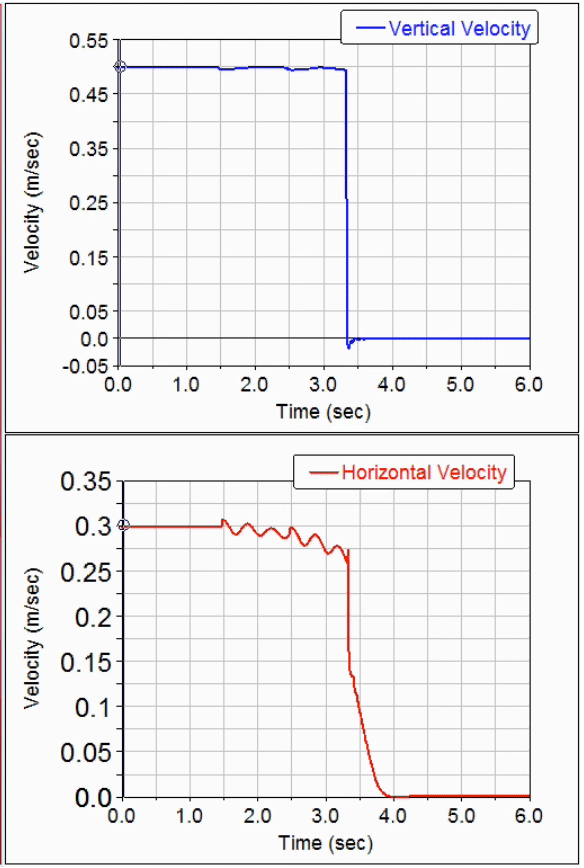
Adaptable Lander Stabilizers to:

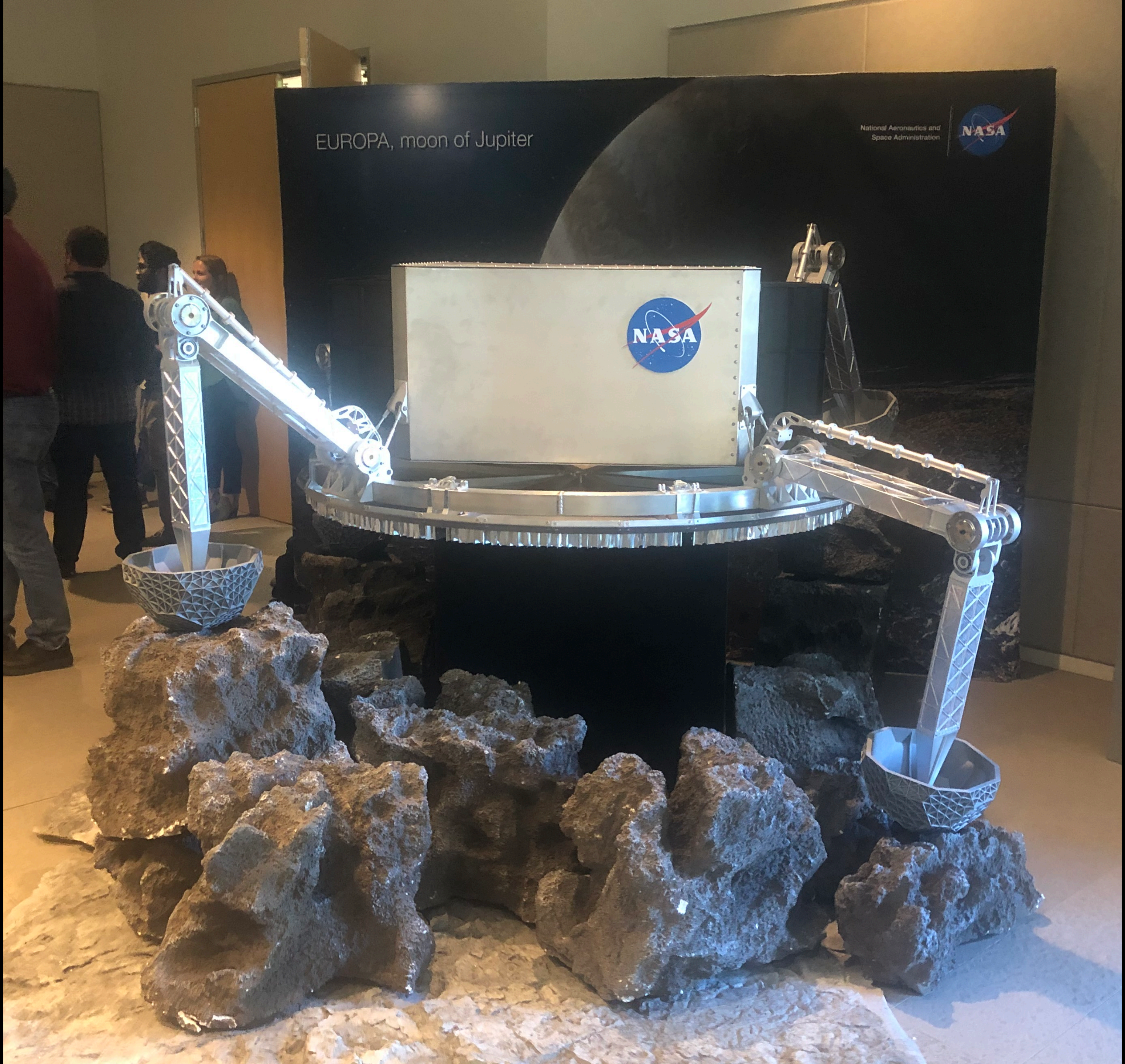
- reduce post landing deck tilt
- improve lander stability in order to facilitate sampling operations
- achieving a lower deck altitude in order to facilitate sampling operation

in the presence of large 1m terrain relief





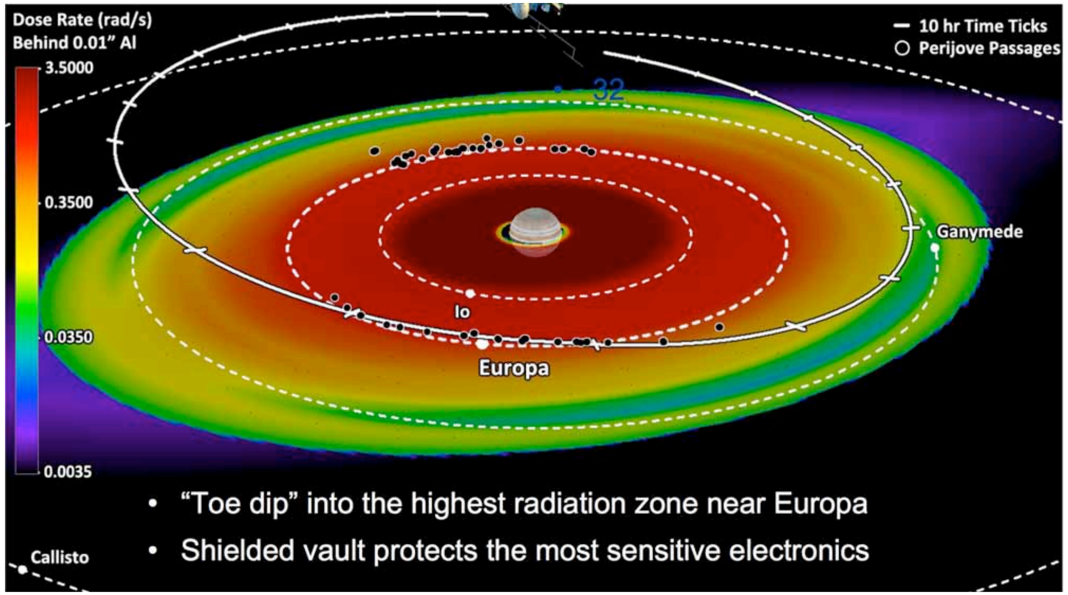



EUROPA, moon of Jupiter
National Aeronautics and Space Administration
NASA
NASA

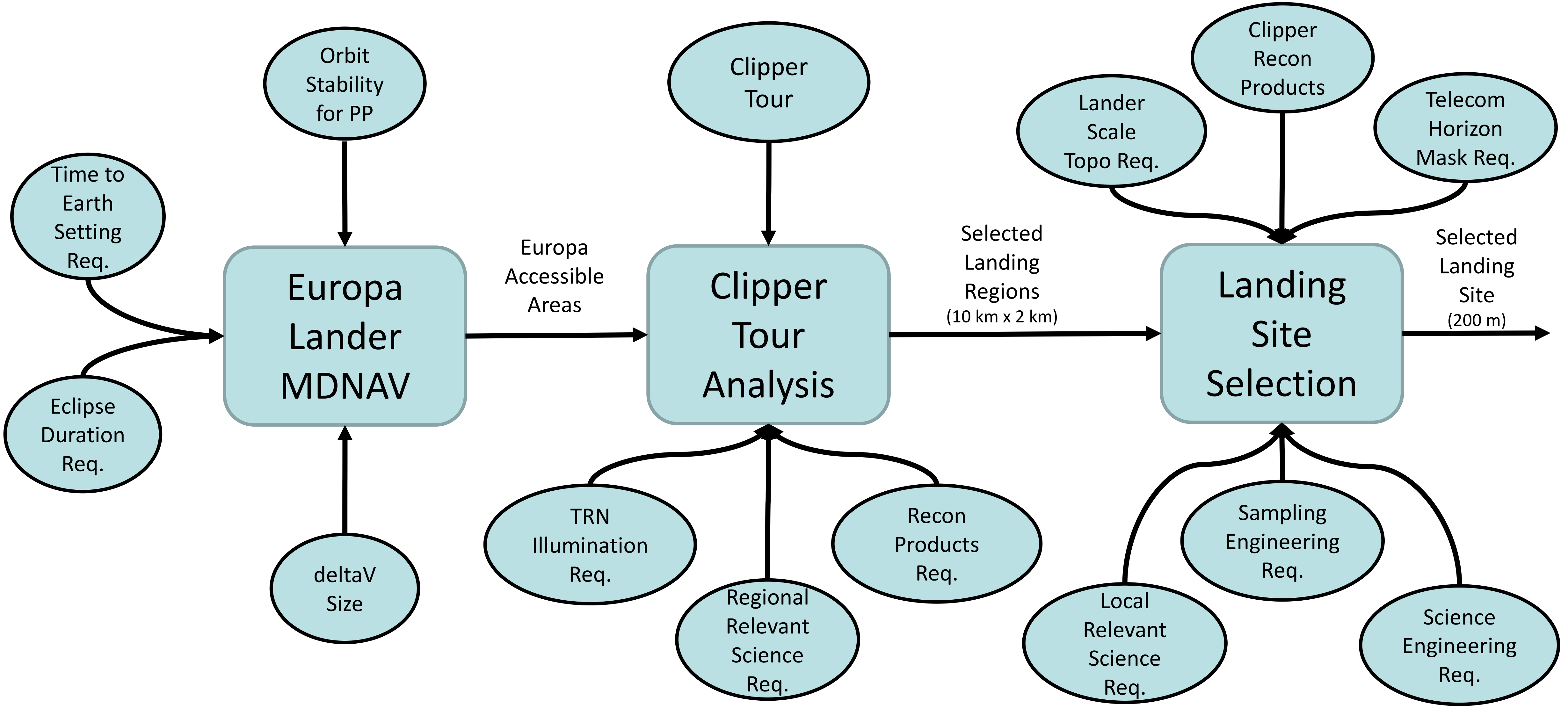
Pillar 5: Radiation Tolerant Avionics

5. Tolerance of radiation induced resets and failures

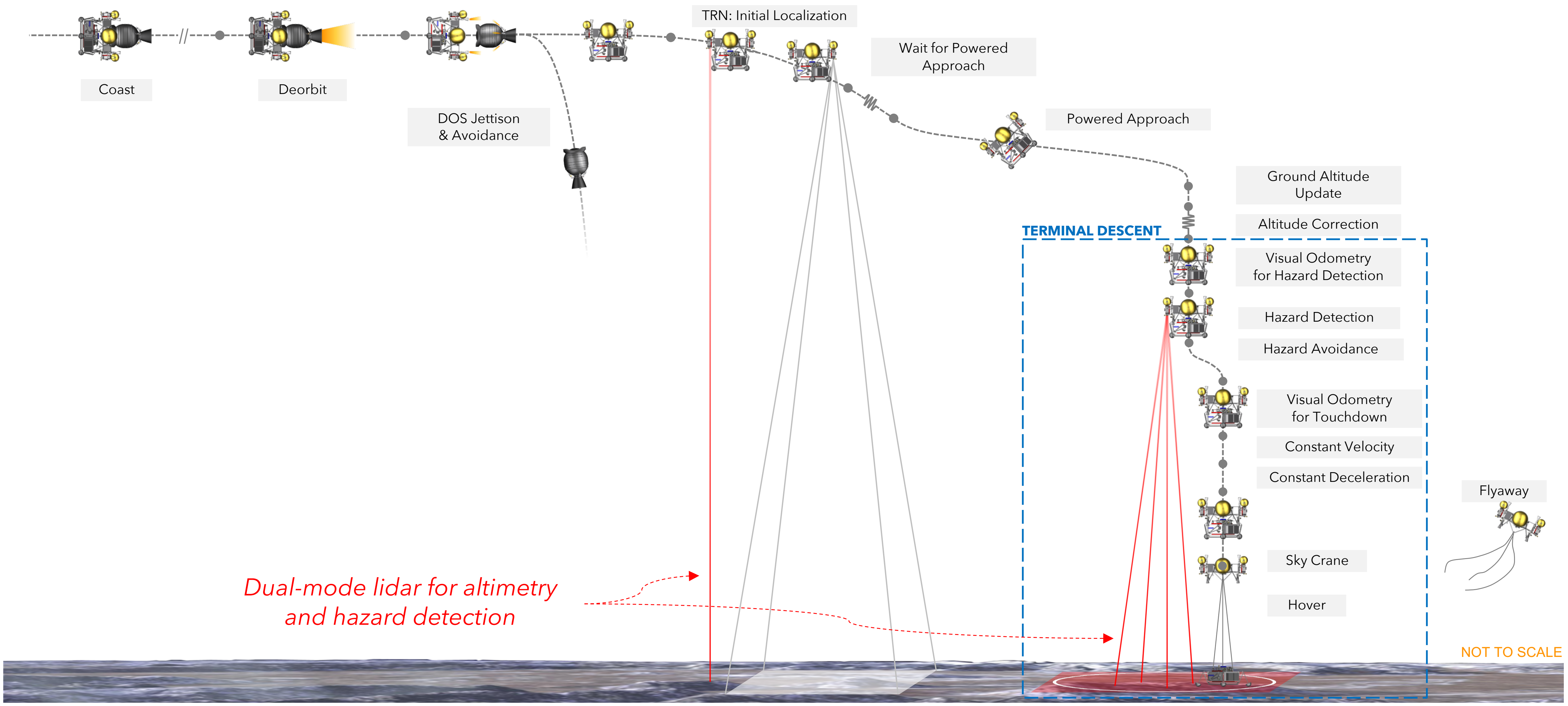
Ultra-high Radiation



Pillar 6: Landing Site Selection Process



DDL Concept of Operations



Comparisons with Viking and MSL

	Viking	MSL	Europa Lander
Reconnaissance at design time	Mariner 9: • Image resolution = 98m	MGS (1997): • Image resolution = 98m MRO (2006): • Image resolution = 0.5m Viking, MPF, MER landers • Image resolution = cm scale	Galileo: • Best image resolution: 6m
Pre-landing reconnaissance	Viking Orbiter: • 200m 100%, 100m 20%, <20m 0.3% • Max resolution = 8m	MRO: • Image resolution = 0.5m	Europa Clipper: • 0.5m from 50km • 1m from 100km
Lander/Rover scale surface models (slopes, rocks)	Lunar Surface Missions	Viking, MPF, MER landers	Earth Analogs Laboratory Experiments
Time between pre-landing reconnaissance and landing	1 month	years	~3 years
Landing ellipse size	174 x 62 mi	14 km x 7 km	200 m
Hazard Detection and Avoidance	No	No	Capability to avoid 10c m hazards
Lander terrain capability	Ground clearance = 22cm	Ground Clearance = 55cm	1m relief in 1.5m scale
Touchdown Velocity	Vertical Velocity = 2.4 m/sec Horizontal Velocity < 1.4 m/sec	Vertical Velocity = 0.7 m/sec Horizontal Velocity < 0.3 m/sec	Vertical Velocity = 0.8 m/sec Horizontal Velocity < 0.3 m/sec

Conclusions

- Landing technologies have evolved since Viking enabling:
  - Reduced landing ellipse size
  - Reduced touchdown velocities
  - On-board Hazard Detection
  - Improved landing gear terrain robustness
- A spacecraft can be designed TODAY that can land on Europa with an acceptable probability of success
- Waiting for the results from Europa Clipper to influence the Lander design would most likely result in no changes from the current design
- Let's do it!